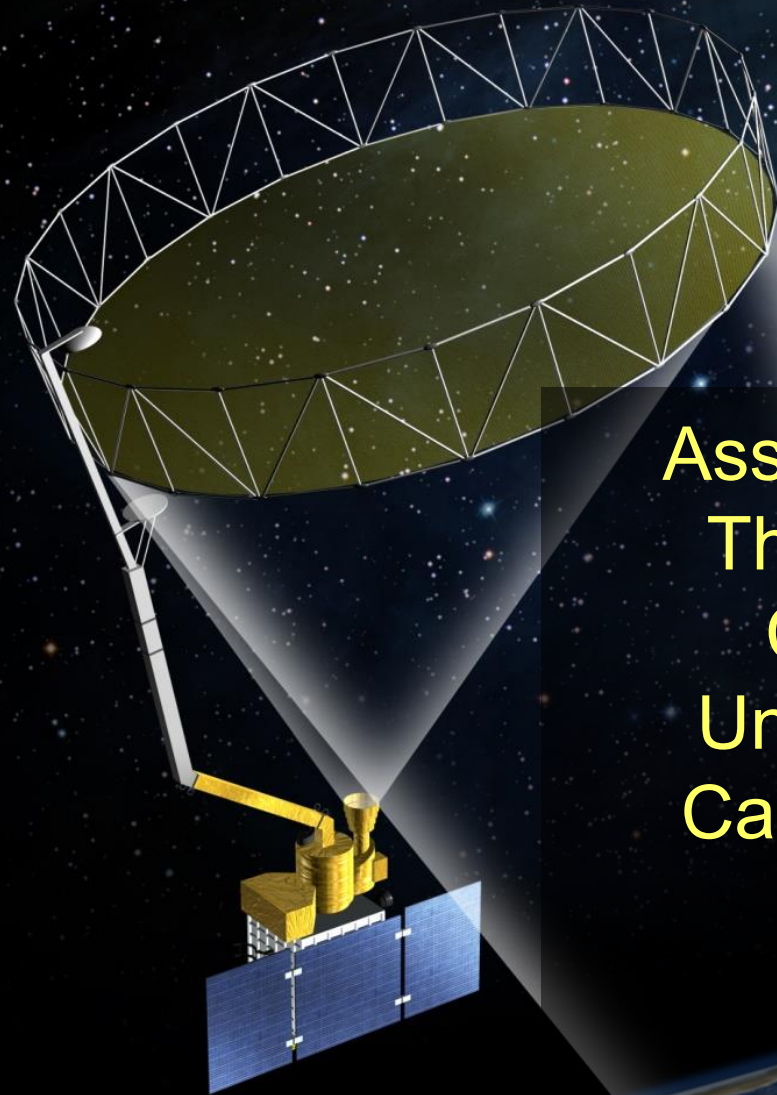




Soil Moisture
Active Passive
Mission
SMAP



Assimilation of SMAP Global Freeze
Thaw (FT) Products to Improve the
CASA Ecosystem Model and Our
Understanding of Northern Latitude
Carbon Fluxes and Wildfire Impacts

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Science Team Meeting #19
May 12-14, 2026
Arcadia, CA

Background



Freeze-Thaw (FT) state of surface soils is a key constraint on Arctic-Boreal water, carbon cycles:

- Shorter dormant period could spur enhanced CO₂ sink activity
- Earlier spring thaws can increase plant water demand, reducing water availability in late summer^{1,2}
- FT-related mortality of soil microbes and fine roots enhances soil CO₂ and CH₄ efflux and nutrient availability³

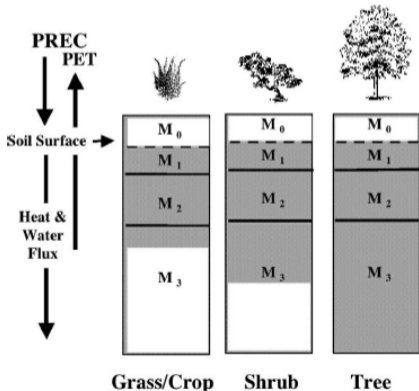
¹Buermann et al. (2013)

²Liu et al. (2019)

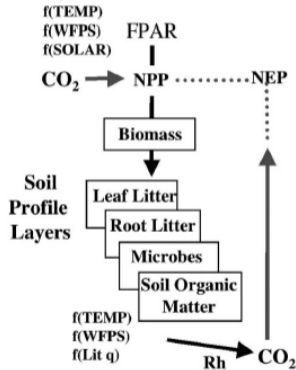
³Gao et al. (2021)

CASA Ecosystem Model Structure

(a) Soil Moisture Balance and Plant Functional Types



(b) Ecosystem Production Nutrient Mineralization

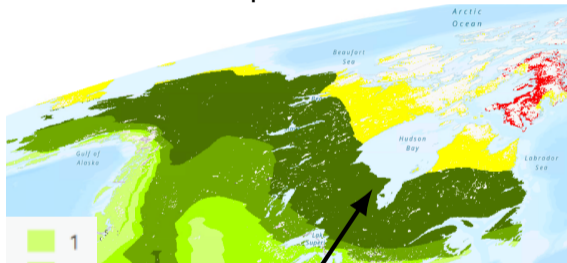


- Simulates heat and moisture fluxes throughout soil column
- Soil freezes based on empirical relationships
- **In baseline CASA version: top layer freezes based on re-analysis air temperature**
- Computes net C uptake, potential ET

FT Constraint with Higher Resolution, Higher Fidelity

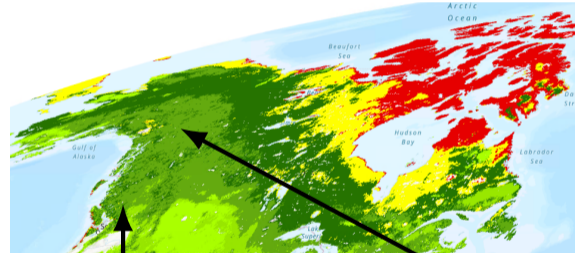
Predicted Month of Thaw (2016)

Baseline - with Gridded Air Temperatures



James Bay

With SMAP F/T

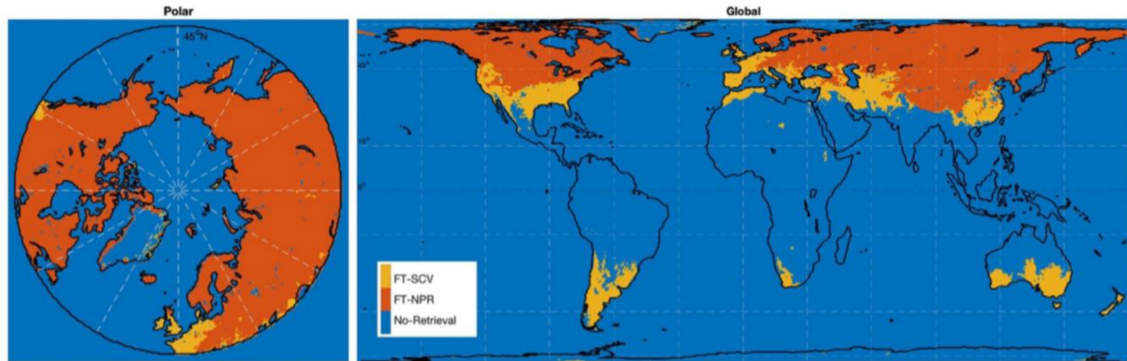


Coastal BC

Yukon

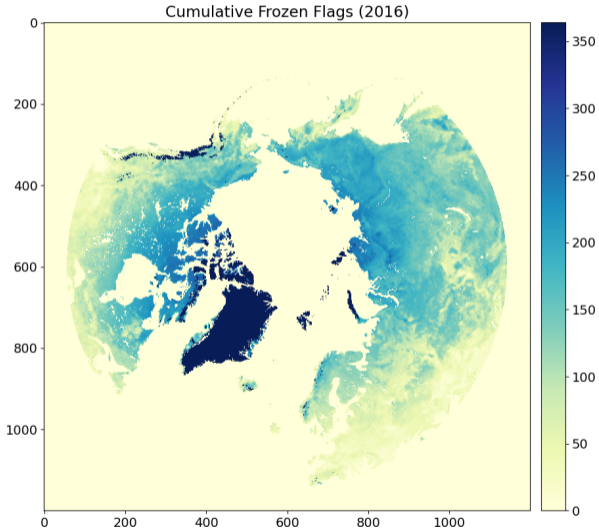


SMAP Level 3 Enhanced (SPL3FT_E) FT Product



- Twice-daily (AM and PM overpasses), 2015 to present
- Dual-pol (NPR) and single-pol (SCV) algorithms, both based on a frozen reference
- Downscaled from 36-km to 9-km resolution using Backus-Gilbert spatial interpolation

SMAP Freeze/Thaw (FT) Product: Known Issues



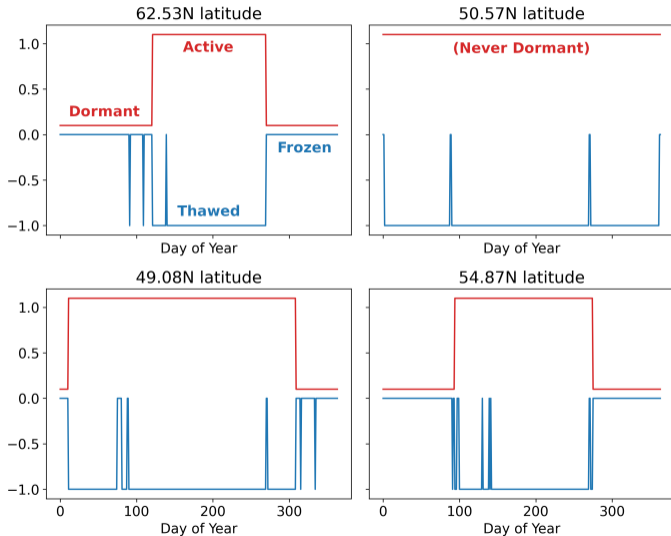
- “Thaw” flag tends to lead soil temp. due to wet snow cover¹
- Anomalous FT states: spurious Thaw flags in Winter and spurious Freeze flags in Summer¹
- Complex terrain, wet snow, insulating snow, and pixel size challenge accurate retrievals, esp. during transition periods^{1,2}
- No Frozen period detected *at all* in some high-latitude areas³

¹X. Xu et al. (2020);

²Kim et al. (2019);

³Bartsch et al. (2025)

Methods: Identifying Start, End of Season



- Active period (for C uptake, unconstrained soil respiration) defined by **Start- (SOS) and End-of-Season (EOS)**
- Given (real or spurious) transient FT states, our approach uses Mixed Integer Linear Programming to **optimize SOS, EOS dates**
- Objective is to minimize sum of Frozen flags during Active period

Results: Validation against Ground Data

USCRN, SCAN Soil Temps.

	Frozen	Thawed
Predicted Frozen	51.7%	48.3%
Predicted Thawed	14.7%	85.3%

FLUXNET Soil Temperatures

	Frozen	Thawed
Predicted Frozen	38.0%	62.0%
Predicted Thawed	18.7%	81.2%

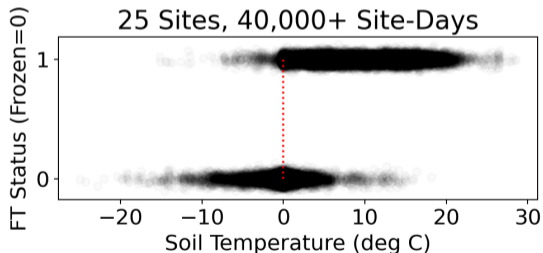
Results: Validation against Ground Data

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FLUXNET Soil Temperatures

	Frozen	Thawed
Predicted Frozen	38.0%	62.0%
Predicted Thawed	18.7%	81.2%



- High Frozen commission error likely reflects insulating effects of (wet?) snow cover, mismatch between soil sensor, SMAP penetration depths
- Freezing-point depression may play a minor role

Results: Air Temperature vs. SMAP FT

When validated against ground temperature at 37 FLUXNET sites, based on monthly aggregates rather than daily data. . .

Using Re-Analysis Air Temp.

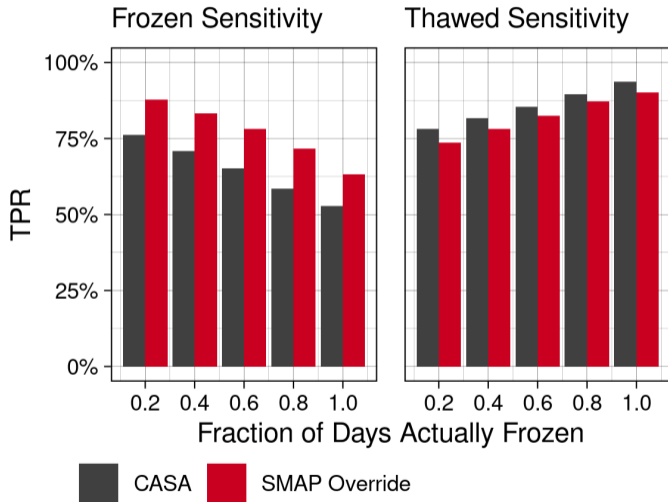
	Frozen	Thawed
Predicted Frozen	68.6%	16.0%
Predicted Thawed	31.4%	84.0%

Using SMAP FT (Monthly)

	Frozen	Thawed
Predicted Frozen	80.6%	19.7%
Predicted Thawed	19.4%	80.3%

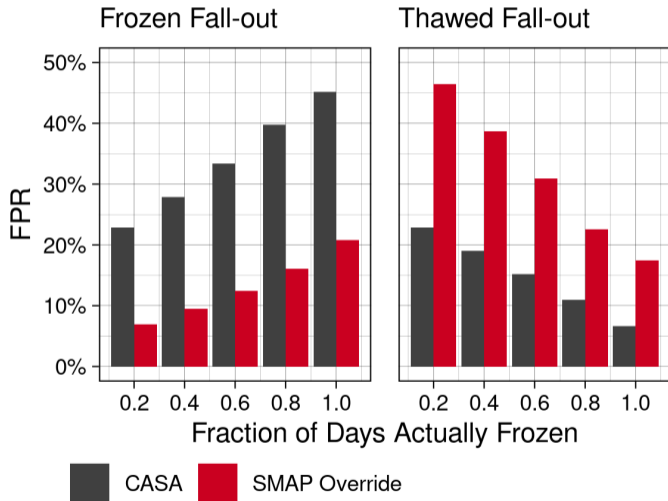
Based on $\geq 50\%$ of daily FT flags are Frozen \rightarrow Frozen for the month

Results: Air Temperature vs. SMAP FT (2)



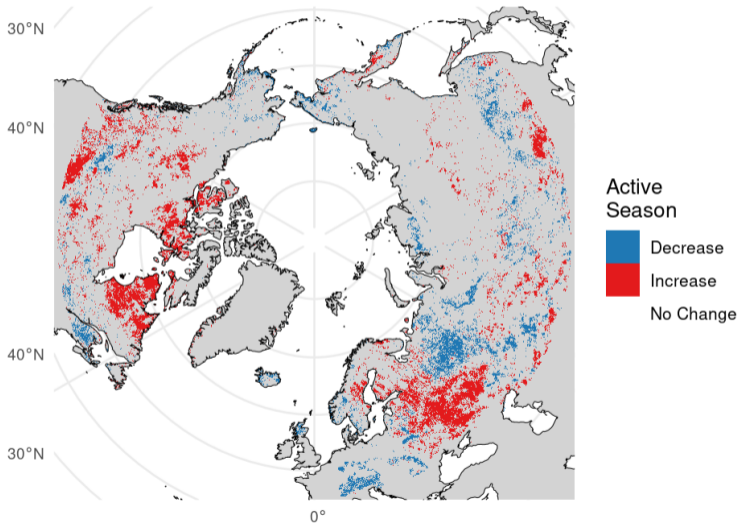
- True Positive Rate (TPR) against EC Tower ground temperatures
- SMAP's lower sensitivity to Thawed state *less severe* than CASA's lower sensitivity to Frozen

Results: Air Temperature vs. SMAP FT (3)



- False Positive Rate (FPR, “False-alarm rate”) against EC Tower ground temperatures
- SMAP’s Thawed FPR similar to CASA’s Frozen FPR, but lower at most cutoffs

Results: Trends in SMAP FT (2016-2025)

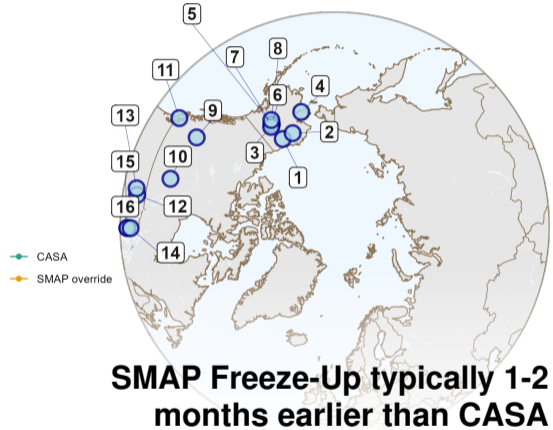
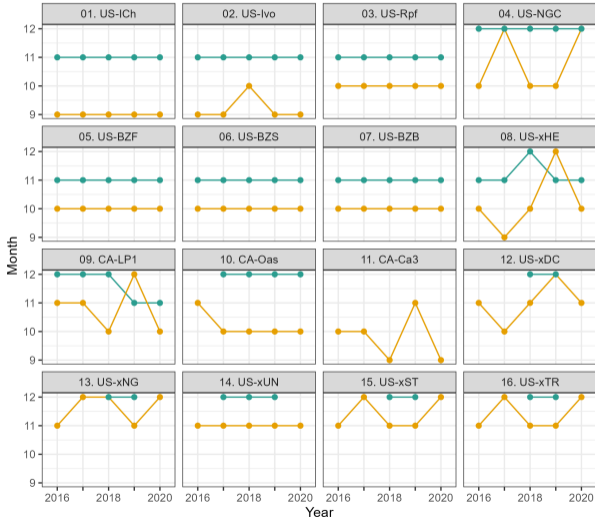


- Generally increasing active season length
- Areas of *decreasing* length correspond to anomalies in SMAP signal?
- e.g., partial recovery of Alps snowpack in recent decades¹, no change in signif. snowmelt date since 2000²

¹Matiu et al. (2021, *The Cryosphere*);
²Vorkauf et al. (2021, *Climatic Change*)

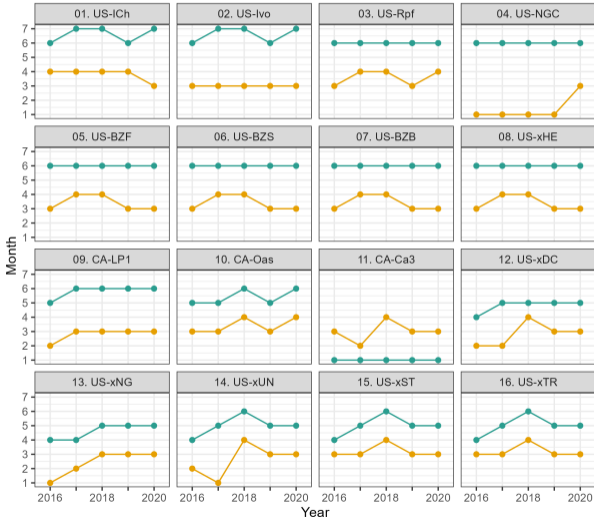
Results: Month of Freeze-Up, SMAP vs. CASA

Month of Freeze by Tower Sites



Results: Month of Thaw, SMAP vs. CASA

Month of Thaw by Tower Sites

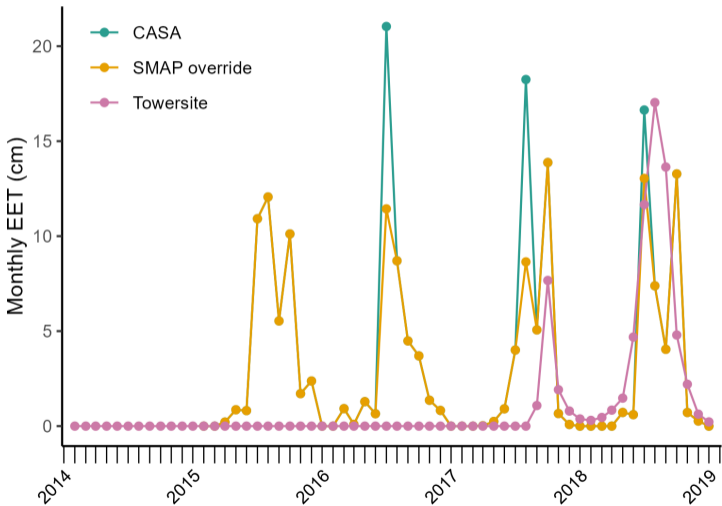


SMAP Thaw date typically 2-3 months earlier than CASA



SMAP F/T Impact on CASA Evapotranspiration (ET)

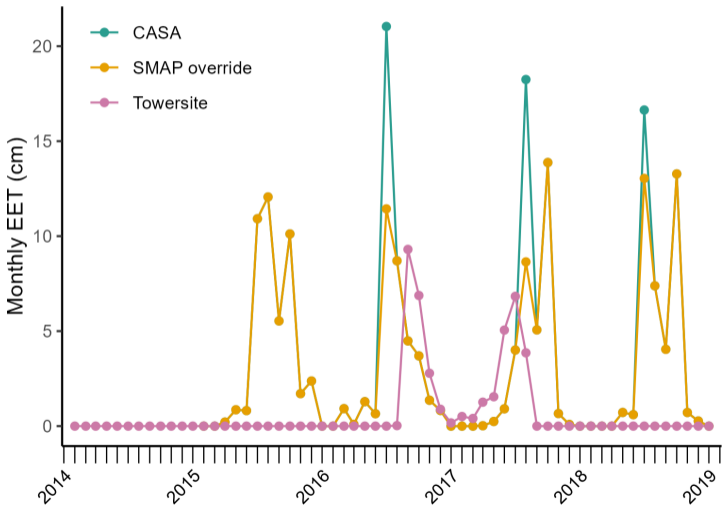
Tower: US-xST (Lat: 45.51 , Lon: -89.59)



SMAP F/T results in delay and reduction of CASA-predicted ET flux

SMAP F/T Impact on CASA Evapotranspiration (ET)

Tower: US-xTR (Lat: 45.49 , Lon: -89.59)

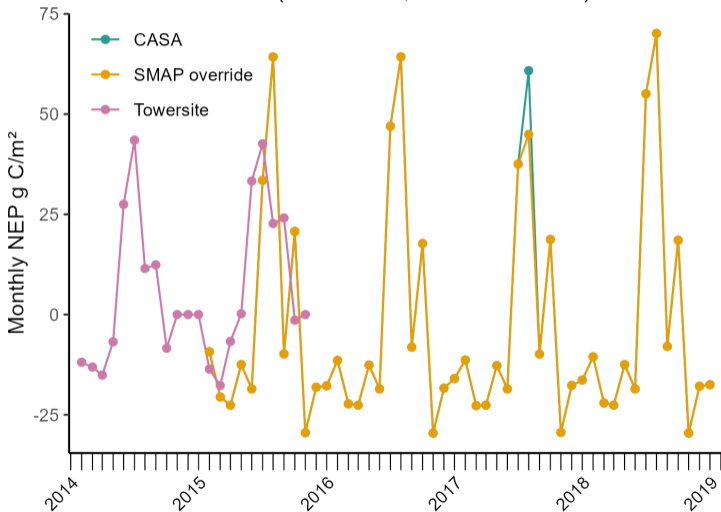


SMAP F/T results in delayed, reduced ET flux, more consistent with tower data



SMAP F/T Impact: CASA Net Ecosystem Production

Tower: US-BZB (Lat: 64.7 , Lon: -148.32)



Lower NEP in 2017, more consistent with tower data(?), may be due to late (SMAP) Thaw in 2017



Upcoming Peer-Reviewed Results



- Scale-up SMAP-Override of CASA predicted ET, NEP, NPP, and soil moisture fluxes to **show global total differences in all biomes above 45 N**
- **Compare dates of MODIS-predicted snow melt** to SMAP-predicted day of thaw to elucidated recent trends
- **Map the changes in SMAP/CASA-predicted F/T, ET, NEP, NPP, and soil moisture** in areas impacted by wildfire in N. America over recent decade

Photo by A. Endsley

Thanks! Questions?

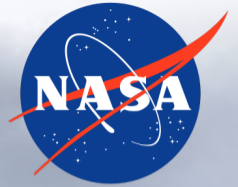


Photo by A. Endsley